# Vorticity and Turbulent Properties in Tidal and Shelf Bottom Boundary Layers

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## LONG-TERM GOAL

Our goal is to contribute to a better understanding of small-scale processes in shallow water and coastal flows, in order to provide better, more physically based parameterizations for coastal models. We seek to understand how high Reynolds' number coastal flows interact with boundaries producing tangential stress, dissipation, mixing, and secondary circulation. Detailed comparison of our field observations with direct numerical simulations will hopefully improve contemporary model parameterization schemes.

## OBJECTIVES

The objective is to observe mean and turbulent flow quantities in an energetic tidal channel over a flat, smooth channel bottom and over topography, and various stratification conditions. These observations throughout the water column are being contrasted with published results from current meters on tripods, from wind tunnel experiments, and theory. Particular emphasis is placed on the observation and interpretation of small-scale vorticity in conjunction with other mean and turbulent flow quantities.

## APPROACH

The approach is to measure vorticity, velocity, dissipation and water properties within bottom boundary layers in local tidal channels with variable bottom topography. The most notable sensor is an electromagnetic vorticity detector, which determines a component of relative vorticity based on the principles of motional induction. An experimental site in Pickering Passage in the South Puget Sound has been selected based on a detailed multi-beam bathymetry survey. Topographic relief is less than 0.3 m for distances of 200 m upstream of the measurement site. Other locations offer regular patterns of bedforms, such as waves with heights of 0.5-1 m and wavelengths of 20-30 m, and a prominent ridge

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about 500-m long, rising 10 m above a flat bottom. In addition to velocity and vorticity, observations of temperature, electrical conductivity, pressure, altitude above the bottom, and turbulent kinetic energy dissipation rate are obtained. Vehicle attitude (i.e., pitch, roll, yaw, pitch-rate and roll-rate) is measured to correct vorticity and velocity for vehicle motion and to rotate observations in true horizontal and vertical components. The instrument can be slowly winched vertically while the vessel is anchored or slowly moving.

## WORK COMPLETED

We have conducted several experiments measuring vorticity and other turbulent properties in Pickering Passage, Washington. Several technical reports have been published. We began scientific analysis last year. One paper describing the details of instrument is in press (Sanford et al. 1998). Another paper presenting some interesting results of data taken in a homogeneous turbulent boundary layer has also been accepted (Sanford and Lien, 1998).

## RESULTS

Our profiling method of EMVM allows us to compare estimates of friction velocity based on the profile method, eddy-correlation method, and dissipation method. We observe two distinct log layers in the bottom boundary layer (Fig. 1). The friction velocity estimated in the upper log layer ($Z > 5$ meter above bottom (m.a.b.)) is 1.8 times of that in the lower log layer ($Z < 3$ m.a.b.). A transition layer exists between 3-5 m.a.b. The friction velocity estimated in the lower log layer based on the profile method (i.e., log-layer fit) agrees with that estimated by the dissipation method using the observed TKE dissipation rate and by the eddy-correlation method using estimated turbulent Reynolds stress in the constant-stress layer. The stress estimated from the upper log layer may not reflect the local bed stress. Many researches have shown that the stress calculated by the profile method, often based on measurements above the lower log layer, is greater than stresses estimated by other methods using measurements closer to the bottom.

Our vorticity measurements in the turbulent bottom boundary layer reveal some important results:

- Eddy diffusivity of vorticity estimated from the observed vorticity flux is similar to the eddy viscosity of momentum estimated from the observed momentum flux (Fig. 2).
- A new method to estimate the bed stress is suggested using the vorticity flux.
- Our simultaneous measurements of turbulent kinetic energy dissipation rate $\varepsilon$ and enstrophy confirm their “text-book” relation, i.e., $\varepsilon = \nu \langle \zeta \cdot \zeta \rangle$.

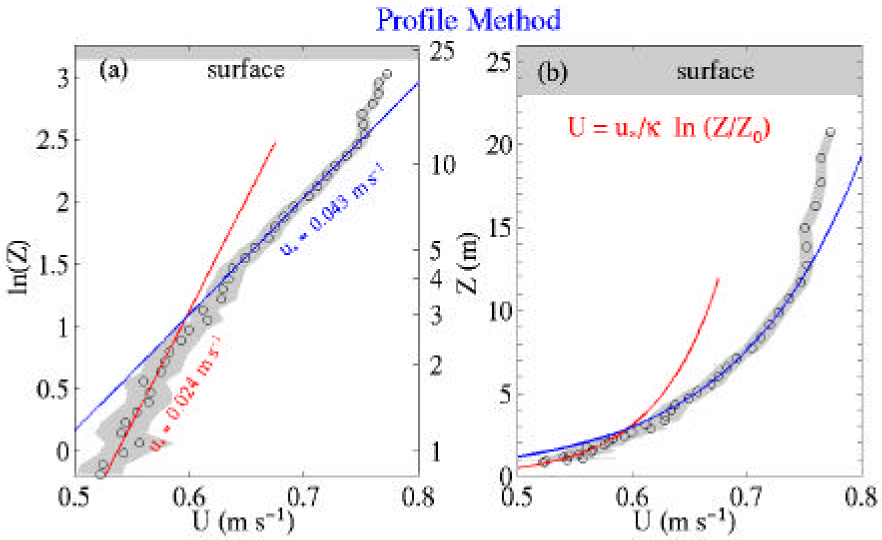
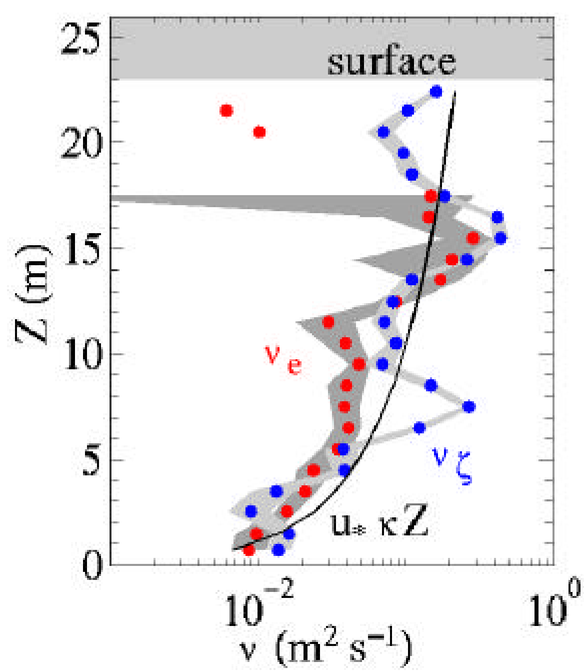



***Fig. 1. Log-layer fits to the mean streamwise velocity. The mean streamwise velocity is plotted as a function of (a) ln(Z) and (b) Z. Note the physical height is indicated on the right hand ordinate of Fig. 1 (a). Circles are observed mean streamwise velocity and shading is the 95% confidence interval. The blue line indicates the log-layer fit in the upper log layer and the red line is the fit in the lower log layer. The log-layer fits are conducted in ln(Z) space and the fit parameters (i.e., $u_*$ and $Z_0$) are applied to obtain the model velocity profiles in panel (b). The shading at the top of each panel represents the range of surface elevations during the 2-3 hours of profiling.***

***Fig. 2. Vertical profiles of eddy diffusivity for vorticity and eddy viscosity for momentum. Blue dots and light shading are the mean eddy diffusivity of vorticity and its 95% confidence interval calculated using the observed vorticity flux. Red dots and darker shading are the mean and the 95% confidence interval of eddy viscosity for momentum. The black curve is the eddy diffusivity prediction used in some turbulence boundary layer models with $u_*$ = 0.024 m s$^{-1}$.***



## IMPACT/APPLICATION

Our instrument provides the first field measurements of turbulent vorticity and vorticity flux in a tidal turbulent boundary layer. Vorticity is the most fundamental variable of turbulence. Therefore, our measurements open up new ways to study turbulence. There are varieties of potential application of our measurements in the ocean. In particular, our instrument is suitable for measuring the vortex force, which is a major driving mechanism of Langmuir circulation and sediment suspension. The instrument can be used to measure potential vorticity providing additional density sensors. Since internal waves do not carry potential vorticity, it is the key quantity to distinguish internal waves and turbulence in a stratified flow.

Further study of form drag in the turbulent boundary layer is needed. We demonstrate that the profile method may yield a non-local stress estimate, which depends crucially on the upstream condition of bottom topography. To study the turbulent boundary layer, it is important to know the surrounding bathymetry. Previous researches have often shown that the profile method yields an excess stress. Form drag has been suggested for the excess stress. We need direct evidence for the suggested form drag.

## TRANSITIONS

There are several possible transitions to Naval applied projects in the field of wake studies and EM signals in the ocean.

## RELATED PROJECTS

It is certain that the sensor is appropriate for participation with many science projects now underway in shallow water bottom boundary layers, such as the CMO project, to study mixing, internal waves, and bottom stress.

## REFERENCES

Sanford, T. B., J. A. Carlson, J. H. Dunlap, M. D. Prater, and R.-C. Lien (1998), An electromagnetic vorticity and velocity sensor for observing finescale kinetic fluctuations in the ocean, *J. Atmos. Oceanic Technol.*, in press.

Sanford, T. B., and R.-C. Lien (1998), Turbulent properties in a homogeneous tidal bottom boundary layer, *J. Geophys. Res*., in press.

## PUBLICATIONS

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